SEE and TID Testing of Space Photonics HMP1-155TRX Series Fiber Optic Transceivers for the Express Logistics Carrier (ELC) Program

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I. Introduction

This study was undertaken to determine the single event destructive and transient susceptibility of active semiconductor die within Space Photonics single channel fiber optic transceivers (HMP1-155TRX) for transient interruptions in the output signal and for destructive events induced by exposing it to heavy ion beams (Ar, Ne, Kr, and Xe) at the TEXAS A&M Cyclotron Single Event Effects Test Facility. Further, protons were utilized to determine SEE and TID effects at the UC Davis Crocker Nuclear Lab Cyclotron. These tests were performed for and supported by the NASA-ELC program. It should be noted that TID requirements for the purposes of the ELC program are minimal at 12krad-Si. Therefore and though Space Photonics 2500 series hybrids have exceeded TID over 1Mrad-Si with no apparent adverse or permanent SEE or TID effects, the 155 series hybrids have only been tested in accordance with ELC requirements.

II. Devices Tested

The sample size for heavy ion testing was two (2) HMP1-155TRX hybrid devices and three (3) HMP1-155TRX hybrid devices for proton testing. The active parts of interest within the transmitter (TX) portion of the hybrid include a laser driver IC designed to operate from 100Mbps up to 2.5Gbps and a semiconductor laser designed to operate up to 2.5Gbps. The receiver (RX) portion includes a trans-impedance amplifier (TIA), a limiting amplifier (LA), both designed to operate from 100Mbps up to 200Mbps, and a semiconductor photodetector designed to operate at data rates up to 2.5Gbps. The devices utilize 1310nm wavelength and 100/140 multi-mode fiber (MMF) optical cable. The overall dynamic range of the TX is -7dBm to 7dBm, optimally, with a maximum RX sensitivity near -38dBm. Per the original ELC-HRDL specification, the TX was to be tuned (or attenuated) to -7dBm output (min) and 0dBm output (max). This is the case that has been evaluated herein. There is an estimated 4dBm of loss inherent to the ELC-to-UMA I/F optical link. Per most recent requests the output power range of the HRDL TX is to be further reduced to -15.6dBm up to -9.0dBm including the 4dBm loss inherent to the link. Therefore the native output from the HRDL TX must remain between -11.6dBm and -5.0dBm in application, either by reducing bias current provided to the laser diode or by optical span attenuation.

III. Test Facilities and Beam Characteristics

The TEXAS A&M Cyclotron Single Event Effects Test Facility was utilized and provided 15 MeV/u ionized Ar, Ne, Kr, and Xe beams, Xe being the most destructive of the four ions utilized. Figure 1 reveals typical 15 MeV/u beam characteristics for these and other heavy ions.

Table 1. 15MeV/u heavy ion beam characteristics at the TAMU Cyclotron

Ion	Total Energy (MeV)	LET to target ($MeVcm^2/mg$)	Range on target (μm)
Xe	1935	75	108
Kr	1260	41	86
Ar	600	12.2	127
Ne	330	3.9	189

The Crocker Nuclear Laboratory (CNL) Radiation Effects Facility at UC Davis was utilized for proton induced SEE and TID testing. The 76" Cyclotron at CNL provides an excellent low to moderate proton energy range from 1.2MeV to 68MeV. The average particle beam flux provided, ranges from tens of particles/cm^2-s up to a very large flux of approximately 10^{11} particles/cm^2-s.

IV. Hardware Configurations and Test Methodologies

For both tests at both locations, the same test setup was utilized. A block diagram of the general BERT and eye-pattern test set configuration can be seen in Figure 2. All test conditions, raw data, etc. are revealed in Tables 1 – 3 in the section that discusses test results. In general and for each device and test location, three primary cases were evaluated – i) RX only in beam, ii) TX only in beam, and iii) combined TRX in beam. Within the hybrid device, the following active parts were targeted – the laser driver (driver) on the TX multichip module (MCM), and the trans-impedance amplifier (TIA) and limiting amplifier (LA) on the RX MCM.

The same BERT and Communications Signal Analyzer (CSA) were utilized for both tests. The BERT is a calibrated Agilent 86130A test system. The CSA is a calibrated Tektronic CSA8000B digital sampling oscilloscope. The BER pattern generator was programmed to send 125Mbps PN7 PRBS data to the optical TX, which was linked to the optical RX by 100/140 MMF optical cable. The RX then received, performed O/E conversion, and amplified the resulting electrical signal that was fed into the BER analyzer for generator comparison. Bit and burst errors were monitored and recorded but not strictly isolated during testing. No error correction was being utilized and pattern sync was maintained throughout. Zero error operation was confirmed as a baseline before beam-on. In most cases, less than five minutes was required to confirm zero error baseline operation with real-time BER less than 1E-10 prior to test run initiation. The CSA was utilized to observe and record NRZ eye-pattern data pre, in-situ, and post. The CSA eye pattern monitoring, in addition to observing in/out of beam current demand characteristics from the power supply, allows for the confirmation of latch-up or SEL, of which none was observed during all testing performed. Due to the power supply requirements of the ELC program, e.g. 3.3V +/- 5%, SEL testing was performed at 3.15V and 3.45V as well as 3.3V. With the TRX differential I/O being DC-coupled rather than AC-coupled, input power levels directly affect differential output signal levels and were therefore evaluated to confirm that no issues exist in the radiation environments of interest. Package base heating was also utilized during heavy ion testing to confirm combined thermal and radiation effects. The maximum package base temperature utilized during heavy ion SEL was 65°C, the maximum anticipated package temperature per thermal analysis results.

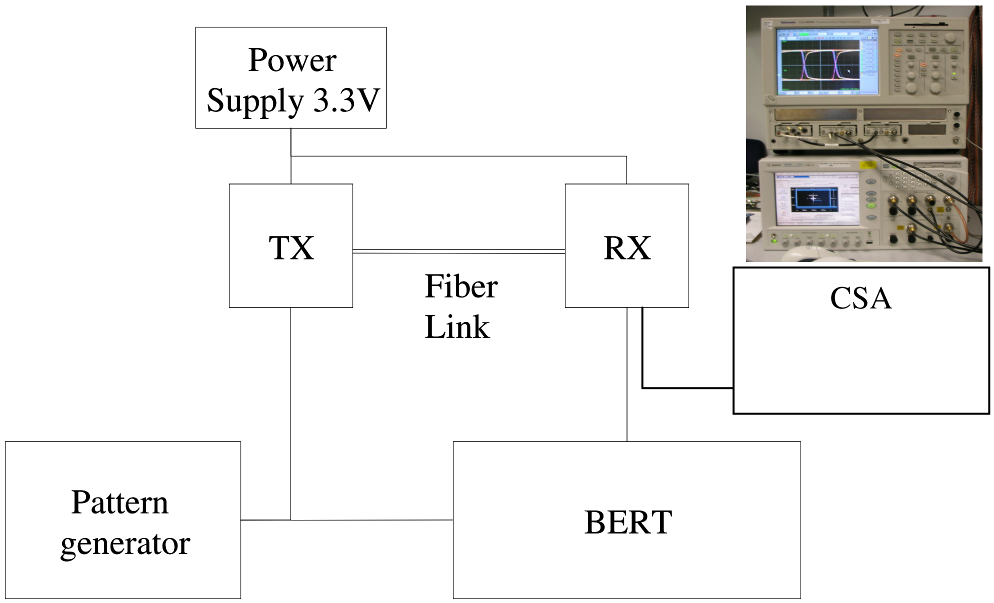

Figure 2. General block diagram of the test setup utilized during HMP1-155TRX hybrid testing.

V. Test Results

Test results from the heavy ion SEE tests can be seen in Table 1. Error cross-section curves for RX and TX when die were irradiated are shown in Figures 3 – 6. Maximum measured cross-section is high (about 10^{-1} cm^2/channel), but LET threshold is high (higher than 70MeVcm^2/mg). Therefore, in-flight sensitivity of active devices will be negligible. Test results from heavy ion SEL tests can be seen in Table 2. Under all conditions utilized no loss of synchronization, SEL or latch-up was observed. Only SEE bit and burst errors were observed.

Table 2. Heavy Ion SEE Test Conditions and Results by Run (TX average output power 0dBm)

Run #	Device in Beam	Actives Targeted	UUT ID	Temp	Ion	Angle	Eff LET ($MeVcm^2/mg$)	Range in Si (um)	Fluence ($\#/cm^2$)	Vcc (V) / Icc (A)	# Bit Errors	X-sec (cm^2)
1	TRX	LA/TIA	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.45/0.33	1009	1.01E-03
2	TRX	LA/TIA	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.45/0.33	983	9.83E-04
3	TRX	driver	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.45/0.33	1223	1.22E-03
4	TRX	driver	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.45/0.33	1114	1.11E-03
5	TRX	driver	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.45/0.33	3176	3.18E-03
6	TRX	driver	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.45/0.33	2829	2.83E-03
7	TRX	LA/TIA	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.45/0.33	3430	3.43E-03
8	TRX	LA/TIA	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.45/0.33	2935	2.94E-03
9	TXonly	driver	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.45/0.33	995	9.95E-04
10	TXonly	driver	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.45/0.33	934	9.34E-04
11	TXonly	driver	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.45/0.33	1573	1.57E-03
12	TXonly	driver	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.45/0.33	1485	1.49E-03
13	RXonly	LA/TIA	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.45/0.33	1072	1.07E-03
14	RXonly	LA/TIA	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.45/0.33	1000	1.00E-03
15	RXonly	LA/TIA	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.45/0.33	2085	2.09E-03
16	RXonly	LA/TIA	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.45/0.33	1959	1.96E-03
17	RXonly	LA/TIA	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.15/0.31	1997	2.00E-03
18	RXonly	LA/TIA	EDU18	RT	Ar	45	12.2	127	1.00E+06	3.15/0.31	1977	1.98E-03
19	RXonly	LA/TIA	EDU18	RT	Ar	0	8.6	180	1.00E+06	3.15/0.31	984	9.84E-04
20	RXonly	LA/TIA	EDU18	RT	Ar	0	8.6	127	1.00E+06	3.15/0.31	1069	1.07E-03
21	RXonly	LA/TIA	EDU18	RT	Ne	0	2.8	127	1.00E+06	3.15/0.31	39	3.90E-05
22	RXonly	LA/TIA	EDU18	RT	Ne	0	2.8	127	1.00E+06	3.15/0.31	26	2.60E-05
23	RXonly	LA/TIA	EDU18	RT	Ne	45	3.9	189	1.00E+06	3.15/0.31	51	5.10E-05
24	RXonly	LA/TIA	EDU18	RT	Ne	45	3.9	189	1.00E+06	3.15/0.31	91	9.10E-05
25	TXonly	driver	EDU18	RT	Ne	0	2.8	127	1.00E+06	3.45/0.33	333	3.33E-04
26	TXonly	driver	EDU18	RT	Ne	0	2.8	127	1.00E+06	3.45/0.33	428	4.28E-04
27	TXonly	driver	EDU18	RT	Ne	45	3.9	189	1.00E+06	3.45/0.33	596	5.96E-04
28	TXonly	driver	EDU18	RT	Ne	45	3.9	189	1.00E+06	3.45/0.33	462	4.62E-04
29	TXonly	driver	EDU18	RT	Ne	45	3.9	189	1.00E+06	3.15/0.31	463	4.63E-04
30	TXonly	driver	EDU18	RT	Ne	45	3.9	189	1.00E+06	3.15/0.31	529	5.29E-04
31	TXonly	driver	EDU18	RT	Ne	0	2.8	127	1.00E+06	3.15/0.31	413	4.13E-04
32	TXonly	driver	EDU18	RT	Ne	0	2.8	127	1.00E+06	3.15/0.31	320	3.20E-04
33	TXonly	driver	EDU18	RT	Kr	0	29	122	1.00E+06	3.45/0.33	2748	2.75E-03
34	TXonly	driver	EDU18	RT	Kr	0	29	122	1.00E+06	3.45/0.33	2824	2.82E-03
35	TXonly	driver	EDU18	RT	Kr	45	41	86	1.00E+06	3.45/0.33	4034	4.03E-03
36	TXonly	driver	EDU18	RT	Kr	45	41	86	1.00E+06	3.45/0.33	3838	3.84E-03
37	RXonly	LA/TIA	EDU18	RT	Kr	0	29	122	1.00E+06	3.45/0.33	5585	5.59E-03
38	RXonly	LA/TIA	EDU18	RT	Kr	0	29	122	1.00E+06	3.45/0.33	5575	5.58E-03
39	RXonly	LA/TIA	EDU18	RT	Kr	45	41	86	1.00E+06	3.45/0.33	6815	6.82E-03
40	RXonly	LA/TIA	EDU18	RT	Kr	45	41	86	1.00E+06	3.45/0.33	7757	7.76E-03
41	RXonly	LA/TIA	EDU18	RT	Xe	45	75	77	1.00E+06	3.45/0.33	151547	1.52E-01
42	RXonly	LA/TIA	EDU18	RT	Xe	45	75	77	1.00E+06	3.45/0.33	148666	1.49E-01
43	RXonly	LA/TIA	EDU18	RT	Xe	0	53	180	1.00E+06	3.45/0.33	20907	2.09E-02
44	RXonly	LA/TIA	EDU18	RT	Xe	0	53	108	1.00E+06	3.45/0.33	22147	2.21E-02
45	RXonly	LA/TIA	EDU18	RT	Xe	45	75	108	1.00E+06	3.45/0.33	147707	1.48E-01
46	RXonly	LA/TIA	EDU18	RT	Xe	15	55	77	1.00E+06	3.45/0.33	32525	3.25E-02
47	RXonly	LA/TIA	EDU18	RT	Xe	15	55	104	1.00E+06	3.45/0.33	31392	3.14E-02
48	RXonly	LA/TIA	EDU18	RT	Xe	30	61	104	1.00E+06	3.45/0.33	68299	6.83E-02
49	RXonly	LA/TIA	EDU18	RT	Xe	30	61	93	1.00E+06	3.45/0.33	59849	5.98E-02
50	TXonly	driver	EDU18	RT	Xe	0	53	93	1.00E+06	3.45/0.33	4473	4.47E-03
51	TXonly	driver	EDU18	RT	Xe	0	53	108	1.00E+06	3.45/0.33	4912	4.91E-03
52	TXonly	driver	EDU18	RT	Xe	45	75	108	1.00E+06	3.45/0.33	6210	6.21E-03
53	TXonly	driver	EDU18	RT	Xe	45	75	77	1.00E+06	3.45/0.33	6127	6.13E-03

Table 3. Heavy Ion SEL Test Conditions and Results (TX average output power 0dBm)

Run #	Device in Beam	Actives Targeted	UUT ID	Temp	Ion	Angle	Eff LET (MeVcm^2/mg)	Range in Si (um)	Fluence (#/cm^2)	Vcc (V) / Icc (A)	SEL
54	TRX	driver	EDU18	50C	Xe	0	75	77	1.00E+07	3.45/0.33	No latch
55	TRX	driver	EDU18	50C	Xe	45	53	108	1.00E+07	3.45/0.33	No latch
56	TRX	driver	EDU18	65C	Xe	45	75	77	1.00E+07	3.45/0.33	No latch
57	TRX	driver	EDU18	65C	Xe	0	75	77	1.00E+07	3.45/0.33	No latch
58	TRX	driver	EDU18	50C	Xe	0	53	108	1.00E+07	3.45/0.33	No latch
59	TRX	driver	EDU18	50C	Xe	45	53	108	1.00E+07	3.45/0.33	No latch
60	TRX	TIA/LA	EDU18	50C	Xe	0	75	77	1.00E+07	3.45/0.33	No latch
61	TRX	TIA/LA	EDU18	50C	Xe	45	53	108	1.00E+07	3.45/0.33	No latch
62	TRX	TIA/LA	EDU18	65C	Xe	45	75	77	1.00E+07	3.45/0.33	No latch
63	TRX	TIA/LA	EDU18	65C	Xe	0	75	77	1.00E+07	3.45/0.33	No latch
64	TRX	TIA/LA	EDU18	50C	Xe	0	53	108	1.00E+07	4.0V/0.43	No latch
65	TRX	driver	EDU18	50C	Xe	0	53	108	1.00E+07	4.0V/0.43	No latch
66	TRX	driver	EDU18	65C	Xe	0	53	108	1.00E+07	4.0V/0.43	No latch
67	TRX	TIA/LA	EDU18	65C	Xe	0	53	108	1.00E+07	4.0V/0.43	No latch
68	TRX	driver	EDU14	50C	Xe	0	53	108	1.49E+06	3.15V/0.31	No latch
69	TRX	driver	EDU14	50C	Xe	45	53	108	1.00E+06	3.15V/0.31	No latch
70	TRX	TIA/LA	EDU14	50C	Xe	0	75	77	1.00E+06	3.15V/0.31	No latch
71	TRX	TIA/LA	EDU14	50C	Xe	45	75	77	1.00E+06	3.15V/0.31	No latch
72	TRX	TIA/LA	EDU14	50C	Xe	45	75	77	1.00E+07	4.0V/0.43	No latch
73	TRX	TIA/LA	EDU14	50C	Xe	0	75	77	1.00E+07	4.0V/0.43	No latch
74	TRX	TIA/LA	EDU14	65C	Xe	0	75	77	1.00E+07	4.0V/0.43	No latch
75	TRX	driver	EDU14	65C	Xe	0	75	77	1.00E+07	4.0V/0.43	No latch

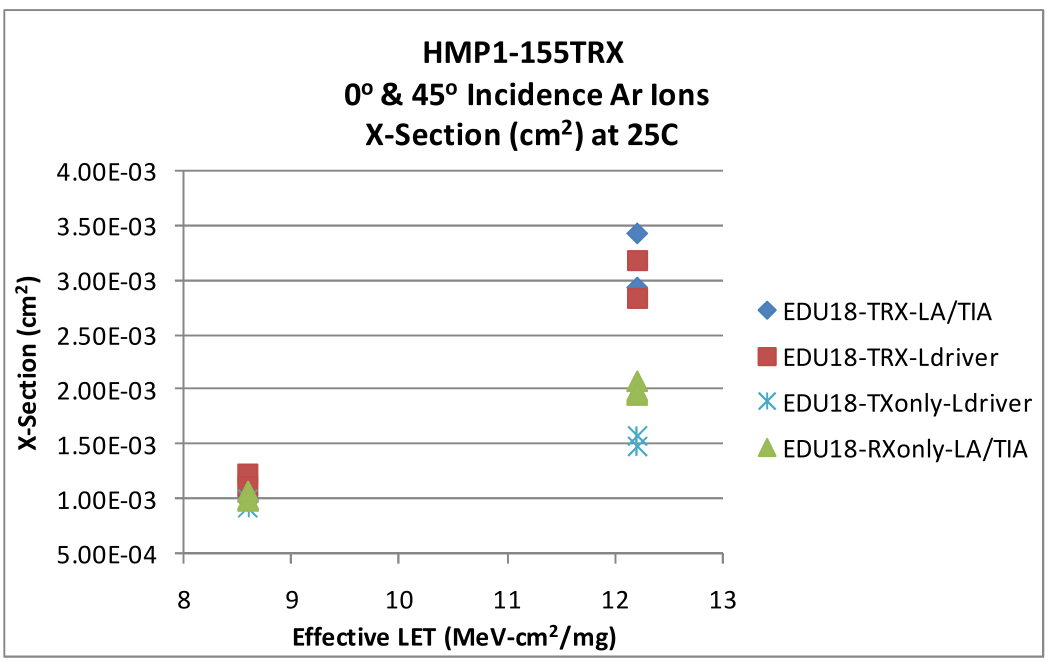

Figure 3. Cross-Section Plotted as a Function of LET for Ar Heavy Ion SEE Tests

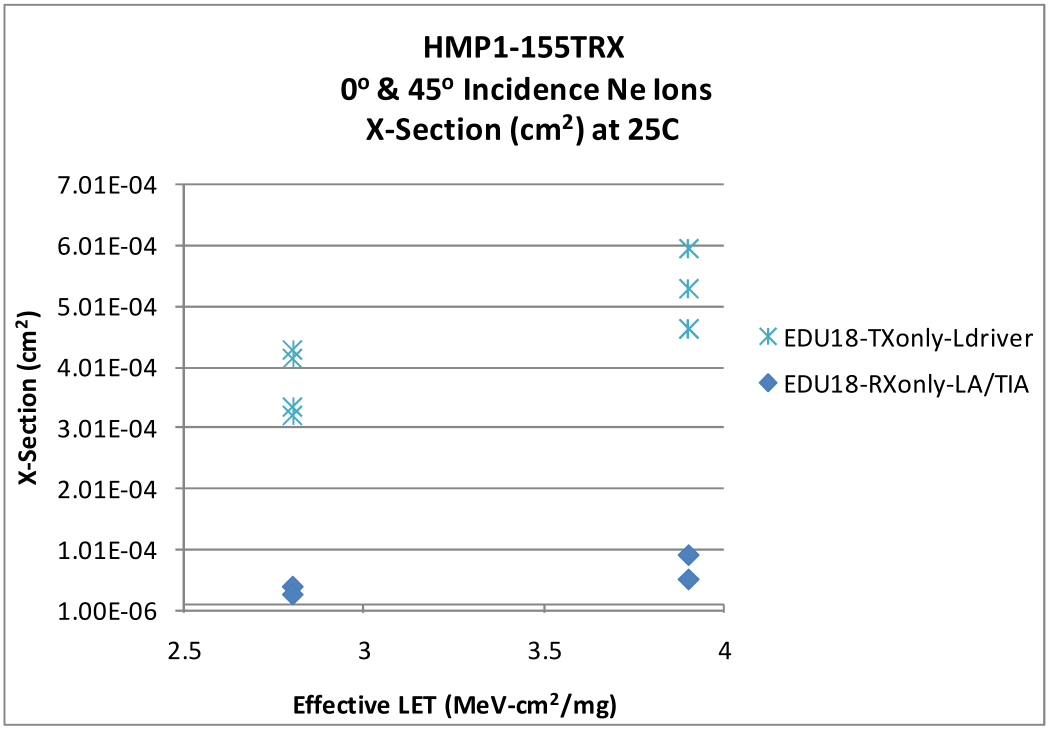

Figure 4. Cross-Section Plotted as a Function of LET for Ne Heavy Ion SEE Tests

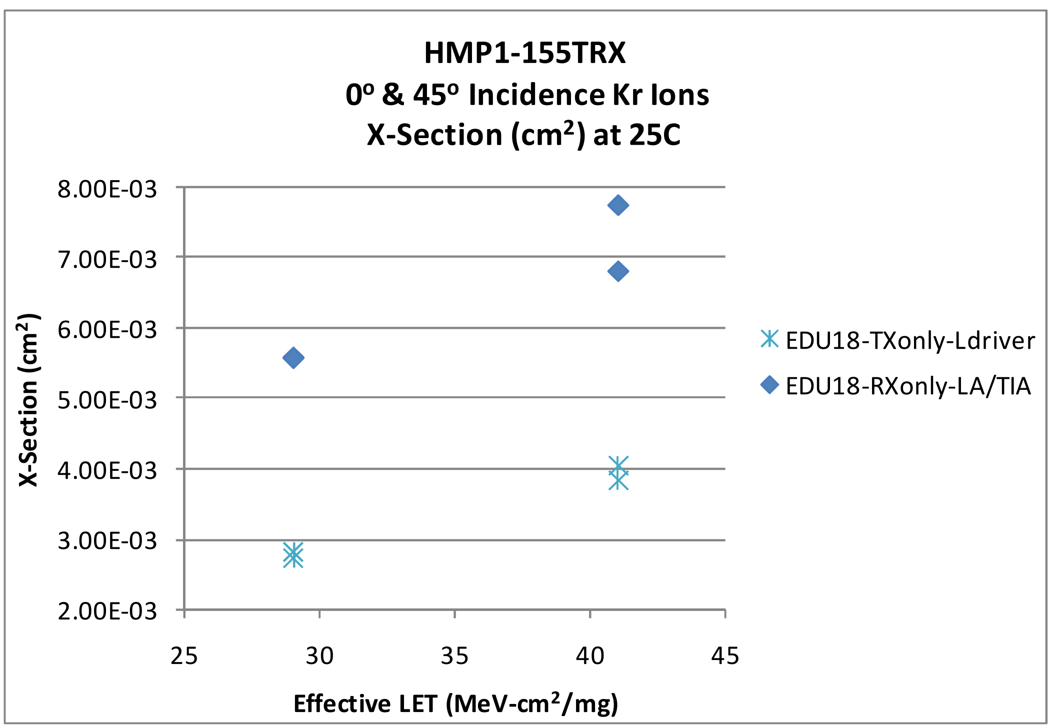

Figure 5. Cross-Section Plotted as a Function of LET for Kr Heavy Ion SEE Tests

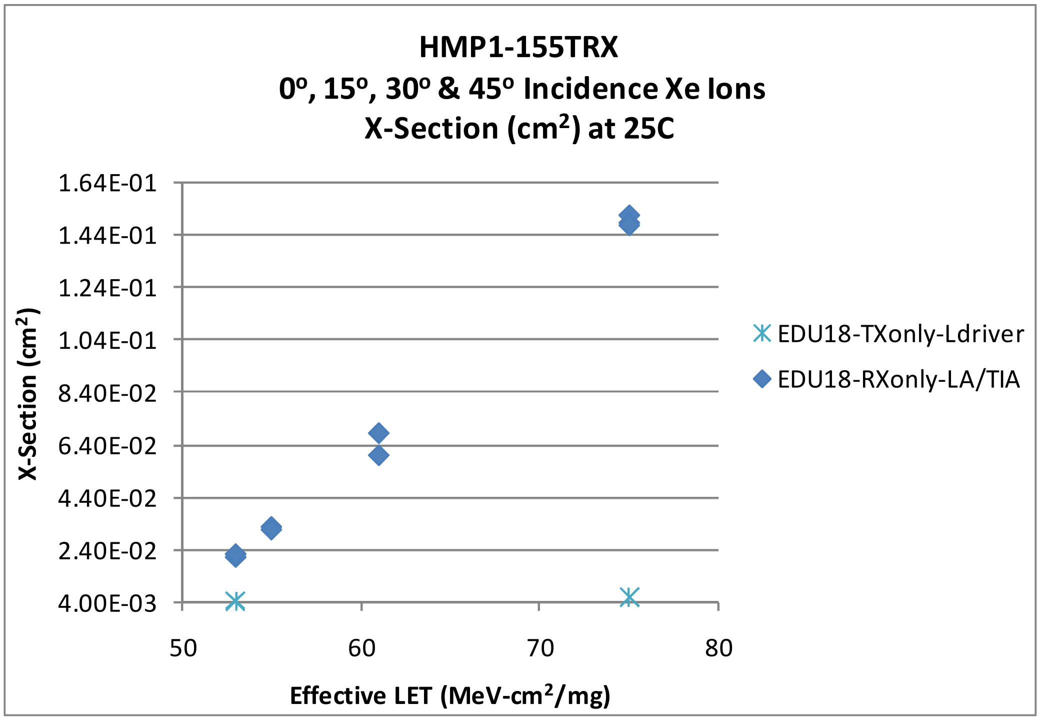

Figure 6. Cross-Section Plotted as a Function of LET for Xe Heavy Ion SEE Tests

Test results from proton SEE/TID can be seen in Table 3. The hybrids withstood well over 12krad-Si TID without loss of synchronization, latch-up or SEL effects with BER maintained less than 1E-9. Figures 7 and 8 reveal cross-section results and TID results for the proton SEE/TID testing. In regards to protons, effective cross-section is relatively low (approximately 1E-8 cm^2). Throughout testing only bit and burst error SEE were observed.

Table 4. Proton SEE/TID Test Conditions and Results (all at ambient temperature with varied optical span attenuation)

Run	UUT	Beam Energy (MeV)	TX Power Output (dbm)	Attenuation (-dB)	Power at RX (dBm)	Incremental Fluence (1/cm^2)	Cumulative Fluence (1/cm^2)	# of Bit Errors	Max BER	Incremental TID (krads)	TID (krads)	X-section (cm^2)
1	ETU10 TRX	63.3	4.25	5	-0.75	7.48E+09	7.48E+09	74	4.80E-10	1.00E+00	1.00E+00	9.89E-09
2	ETU10 TRX	63.3	4.25	5	-0.75	3.74E+10	4.49E+10	285	9.35E-10	5.00E+00	6.00E+00	6.35E-09
4	ETU10 TRX	63.3	4.25	5	-0.75	3.74E+10	1.09E+11	250	8.00E-10	5.00E+00	1.45E+01	2.30E-09
5	ETU6 RX only	63.3	1.26	2.5	-1.24	3.74E+10	3.74E+10	2349	7.00E-09	5.00E+00	5.00E+00	6.28E-08
6	ETU6 RX only	10.1	1.26	2.5	-1.24	4.52E+09	4.19E+10	401	2.50E-09	2.50E+00	7.50E+00	9.57E-09
7	ETU6 RX only	27	1.26	2.5	-1.24	1.95E+10	6.14E+10	479	2.00E-09	5.00E+00	1.25E+01	7.80E-09
8	ETU6 RX only	27	1.26	7.5	-6.24	1.24E+10	7.38E+10	4495	1.00E-07	3.18E+00	1.57E+01	6.09E-08
9	ETU6 RX only	63	1.26	0	1.26	3.90E+11	4.64E+11	12090	1.00E-07	1.00E+02	1.16E+02	2.61E-08
10	ETU8 TX only	63	1.26	0	1.26	3.90E+11	3.90E+11	2917	1.00E-08	1.00E+02	1.00E+02	7.48E-09

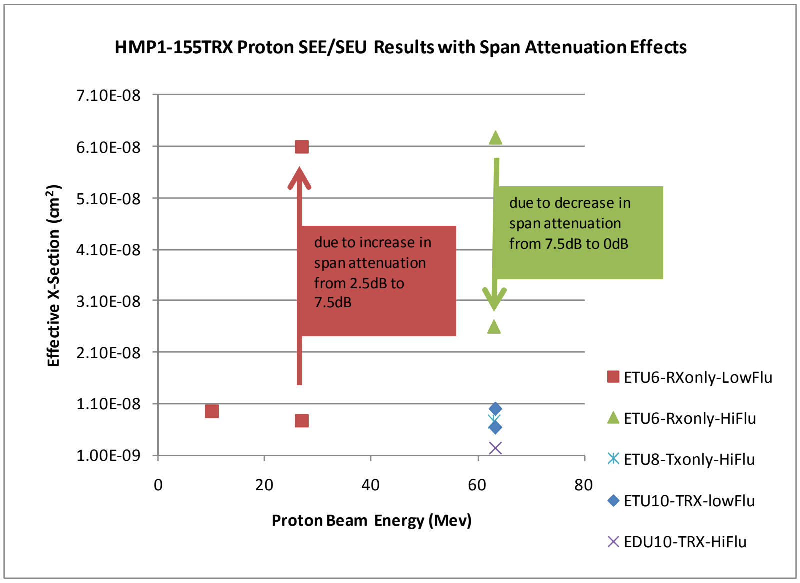

Figure 7. Cross-Section Plotted as a Function of Proton Beam Energy (attenuation effects are identified).

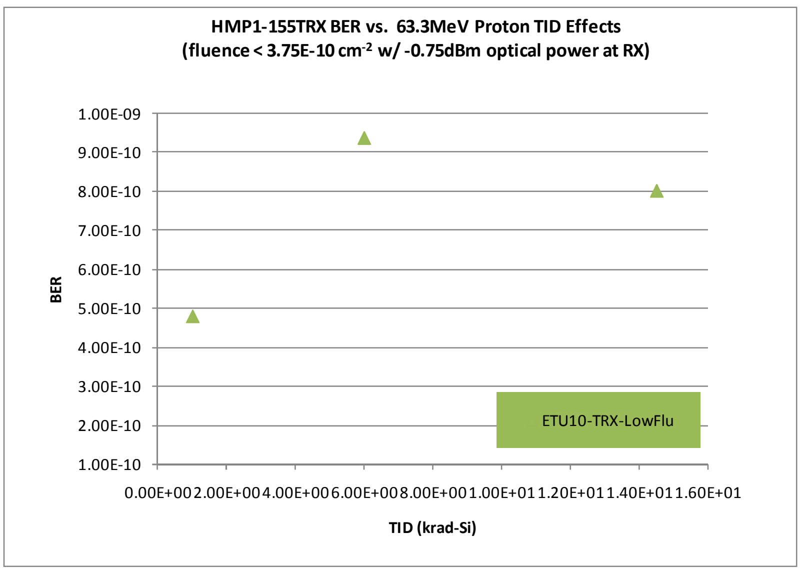

Figure 8. Bit-Error Rate (BER) Plotted as a Function of Proton TID (low fluence).

VI. Conclusions

The active devices utilized within the HMP1-155TRX hybrids are not sensitive to destructive events and their overall SEE sensitivity is low. The hybrids also withstood over 12krad-Si TID without SEL while maintaining BER less than 1E-9 per ISS/ELC specification. However, the data reveals that the RX is relatively more susceptible to SEE than the TX. This is due to the TIA/LA chipset utilized within the RX being designed for very high optical sensitivity (-38dBm); thus, it will be more sensitive to noise generated in ionizing radiation environments than lower sensitivity optical RX devices.